

Advanced Alloys for High Temperature Recuperators

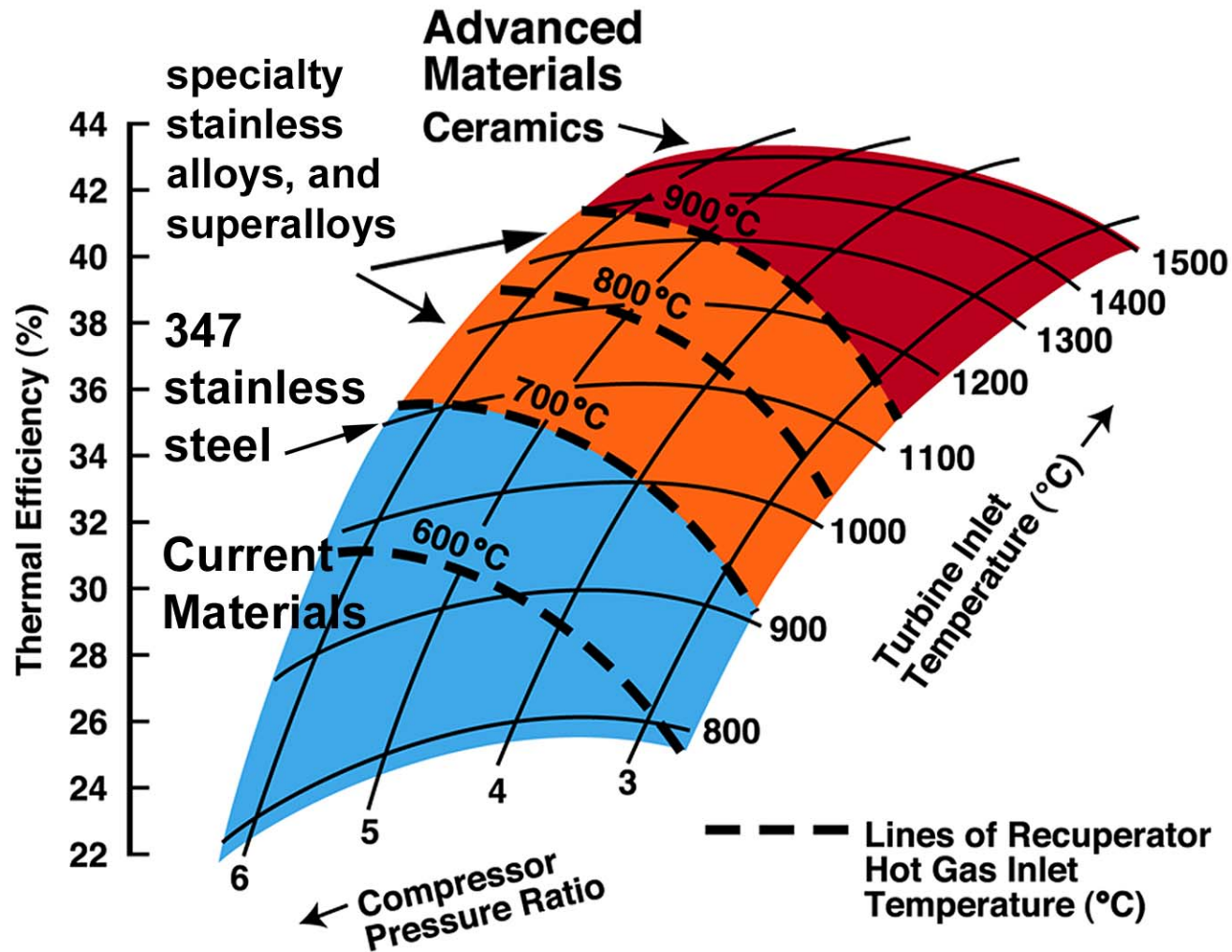
Philip J. Maziasz, Bruce A. Pint,
Robert W. Swindeman, Karren L. More and
Edgar Lara-Curzio

Oak Ridge National Laboratory

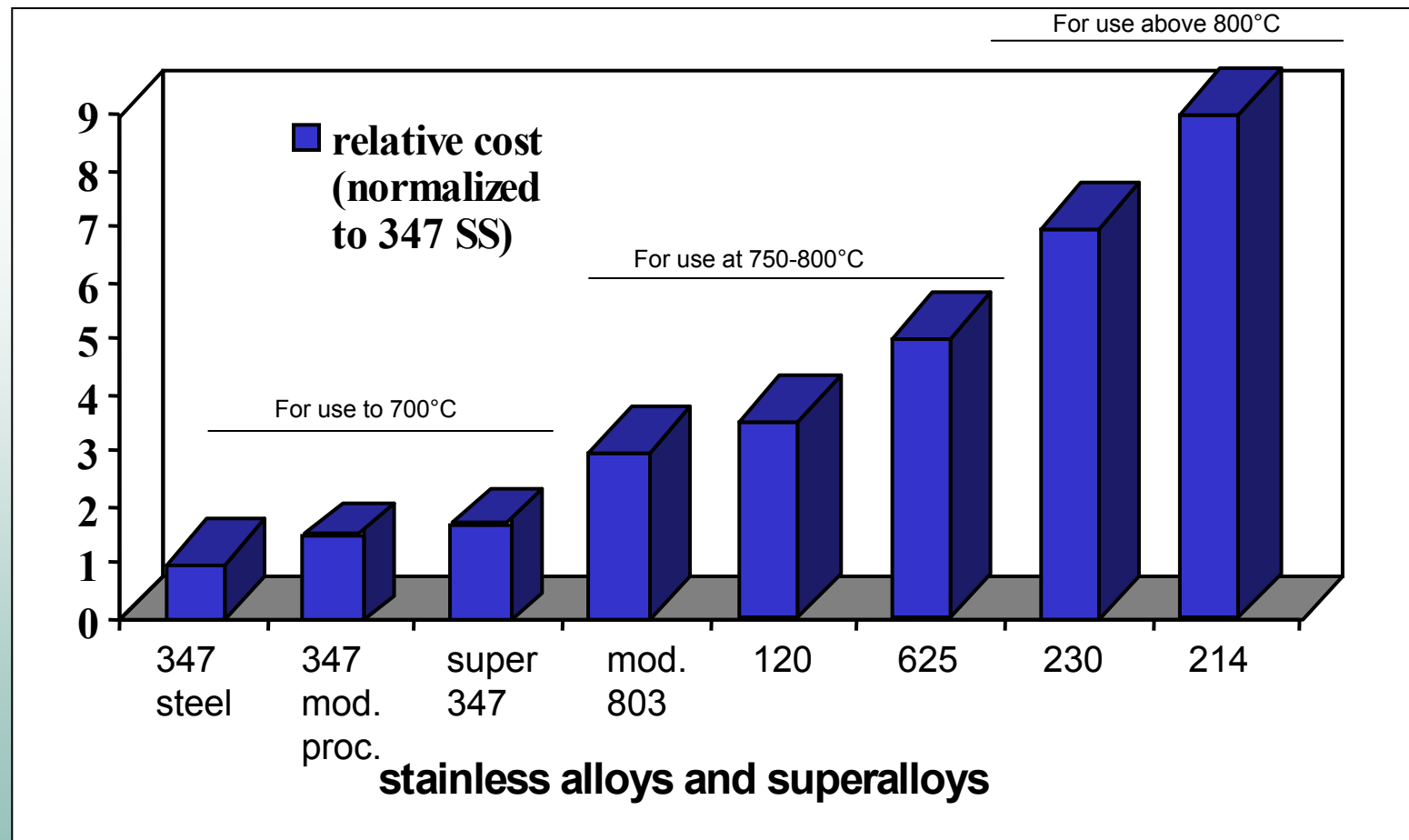
DER Peer Review

March 13, 2002

Materials Selection is Determined by the Recuperator Hot-Gas Inlet Temperature

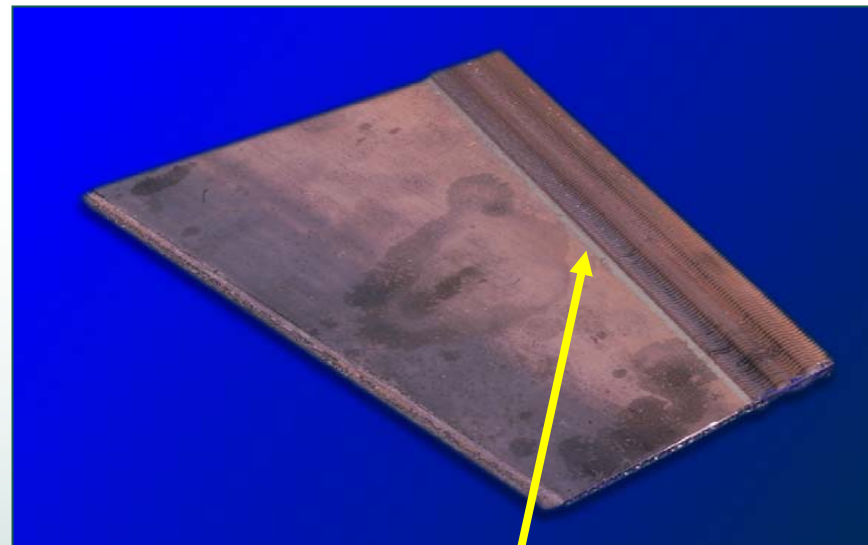
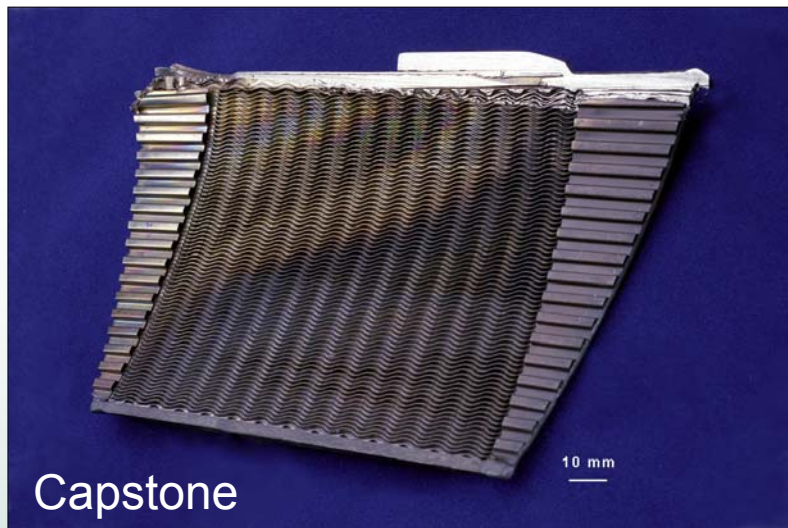


Alloy Selection for Advanced Microturbine Recuperators is Based on Balancing Relative Cost vs. Performance

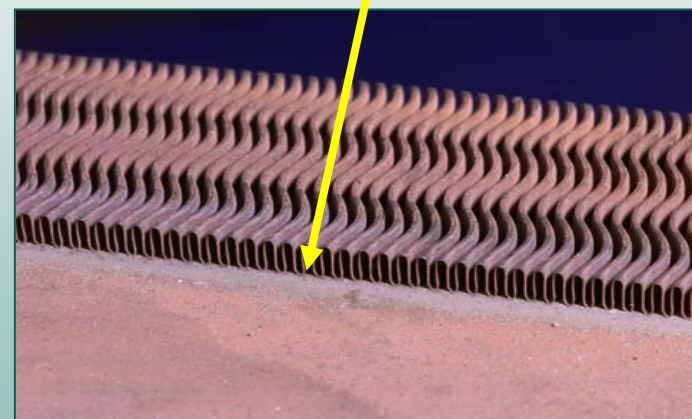


Microturbine Recuperators Are Currently Made From 347 Stainless Steel

Ingersoll-Rand



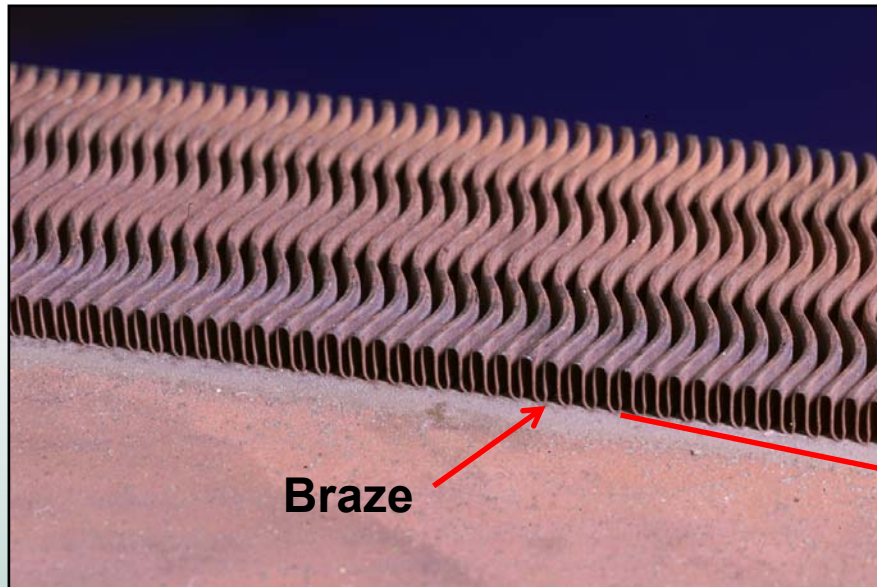
Primary Surface
Recuperator (PSR)



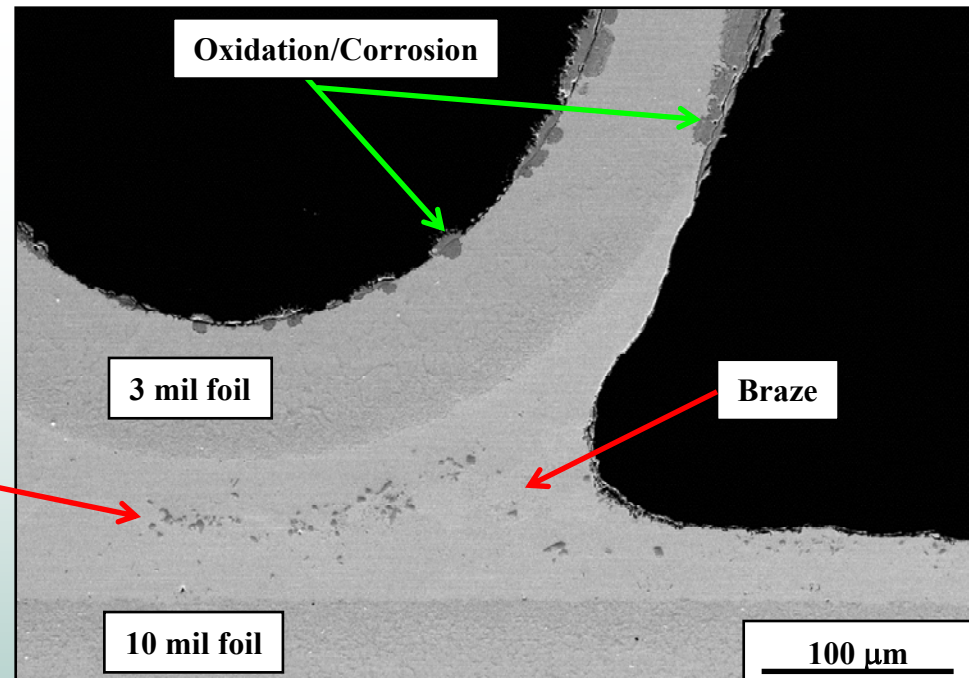
Brazed Plate and Fin
Recuperator (PFR)

Evaluation Of Recuperators With Microturbine Service Will Provide Insight Into Alloy Performance

Ingersoll-Rand plate-and-fin recuperator with over 2,000 h of engine service (no failure)

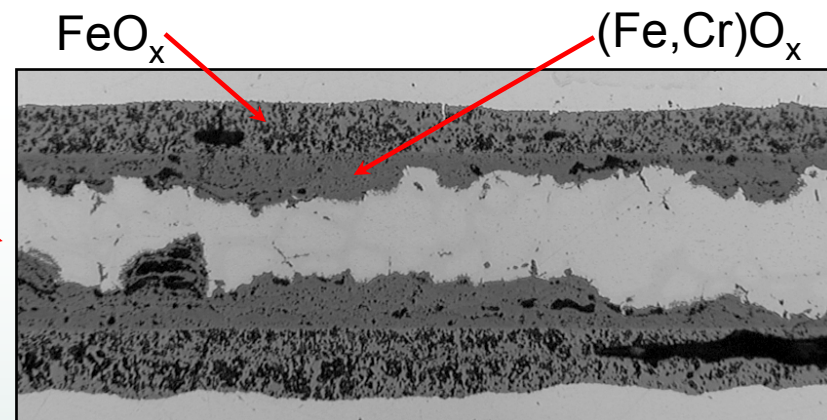
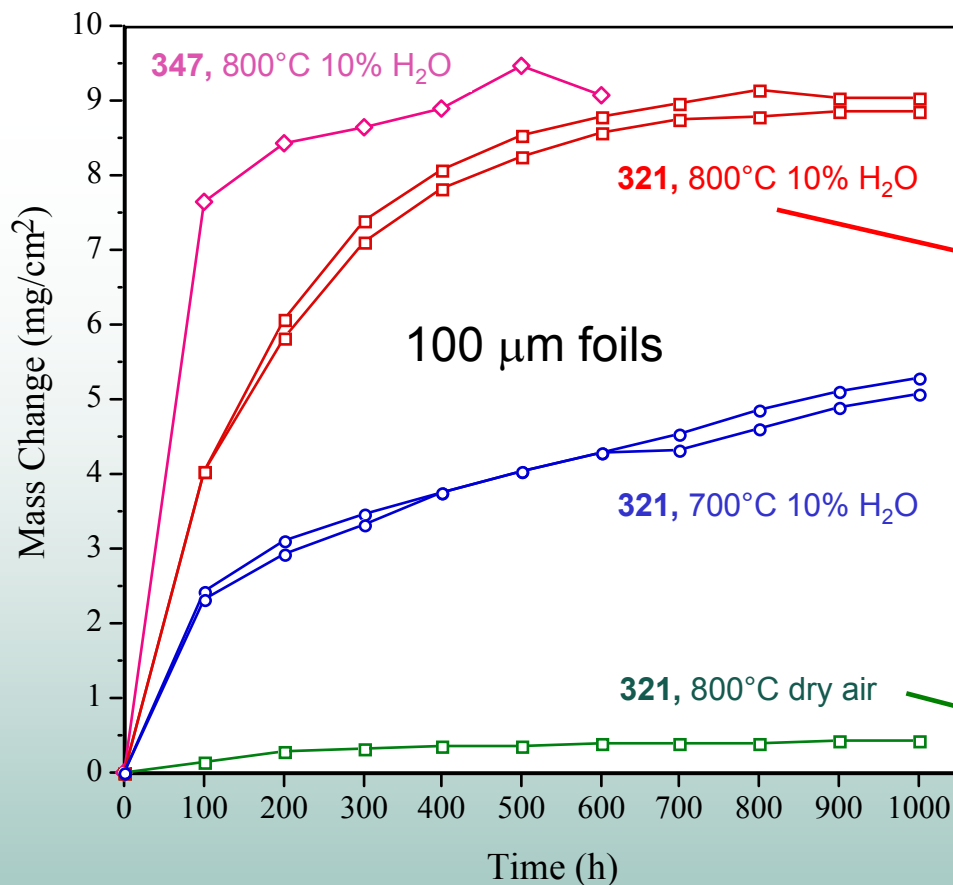


Cross-section SEM image

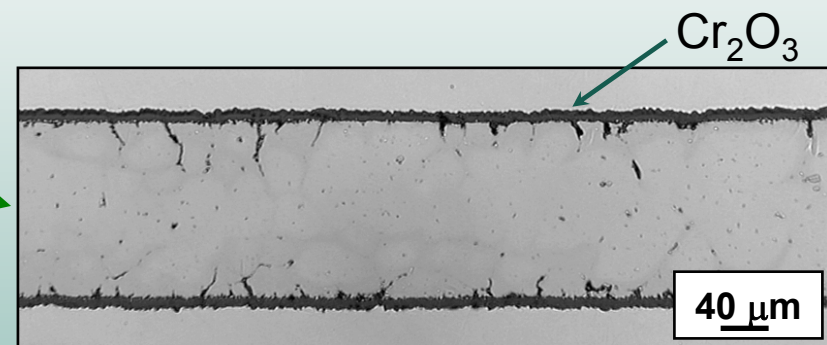


Oxidation found on 347SS foil surfaces is typical of recuperator exposure to microturbine exhaust containing water vapor

Corrosion Problem in Recuperator Applications for Stainless Steel Foils With <20wt.% Cr



321, 1000 h, air+10%H₂O

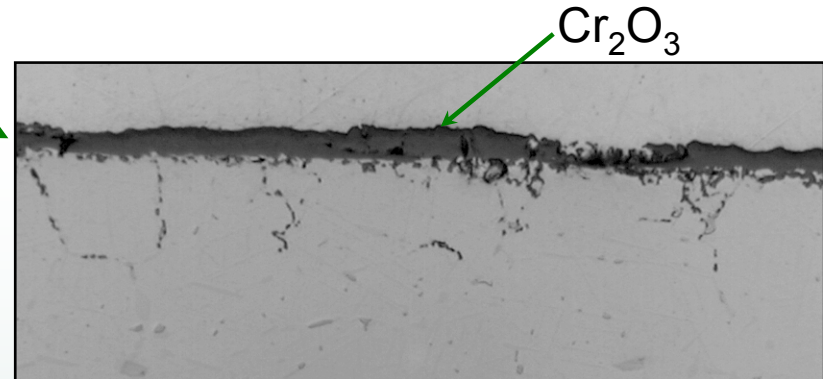
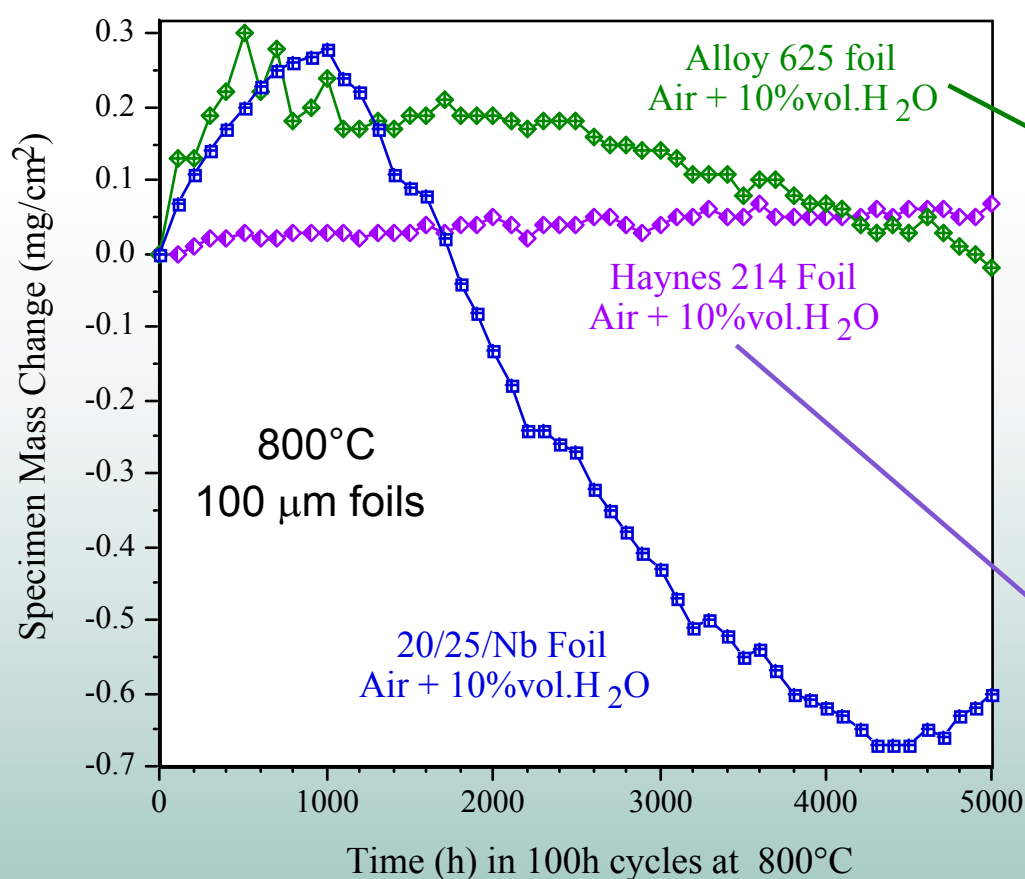


321, 5000 h, dry air

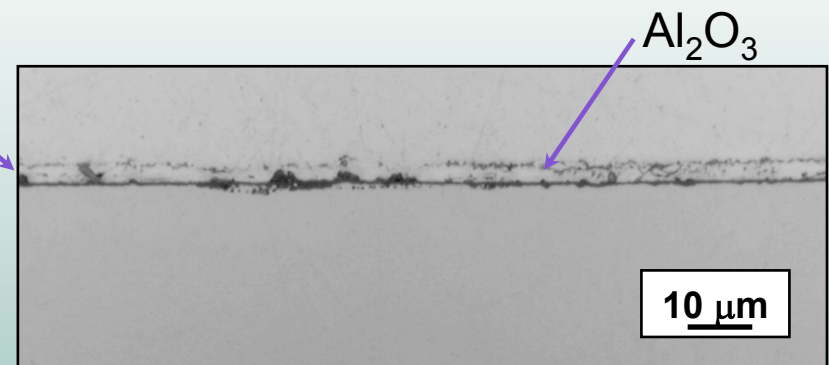
- Short time rapid attack with 10% H₂O compared to lab air
- Eliminates the least expensive alloys from consideration
- Thicker Fe-rich oxide forms instead of more protective Cr₂O₃

More Expensive Alloys Avoid This Problem

Ni- and Fe-Base Alloys With >20wt.% Cr



625, 6000 h, air+10%H₂O



214, 5000 h, air+10%H₂O

- Alloy 625 (Ni-21Cr) and Haynes 214 (NiCrAl) show good resistance
- Even 20/25/Nb stainless steel is resistant at this temperature
(note small mass changes after 5,000 h at 800°C)

What is the least expensive alloy with good corrosion protection?

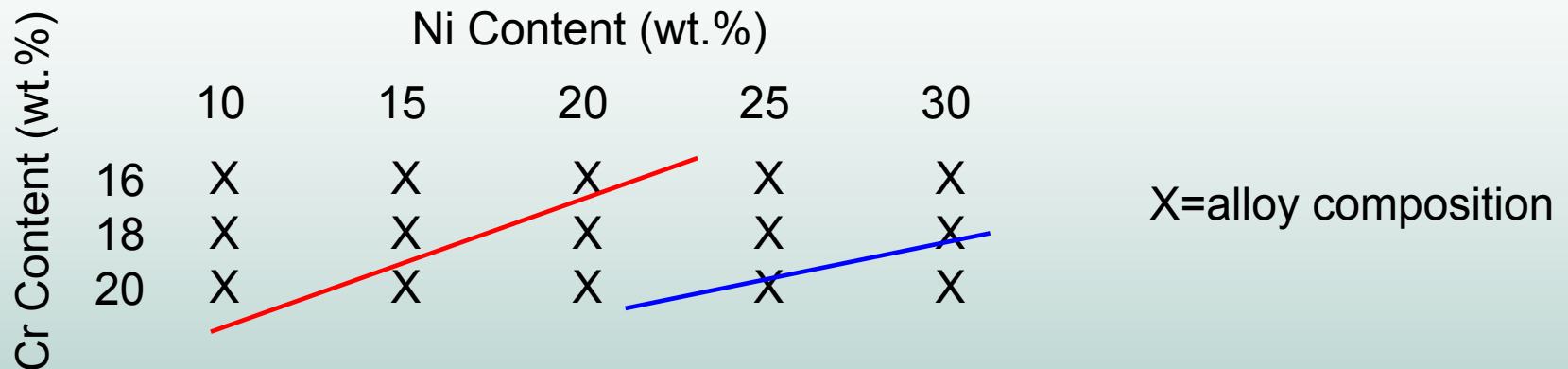
Model Fe-Cr-Ni- Alloy Testing

Study oxidation behavior to assess:

(current work) → effect of Cr and Ni contents

(current work) → effect of alloy grain size

(future work) → effect of minor alloy additions (Mn, Si, Nb, etc.)



Blue line → boundary for as-cast, coarse-grained alloys at 700°C

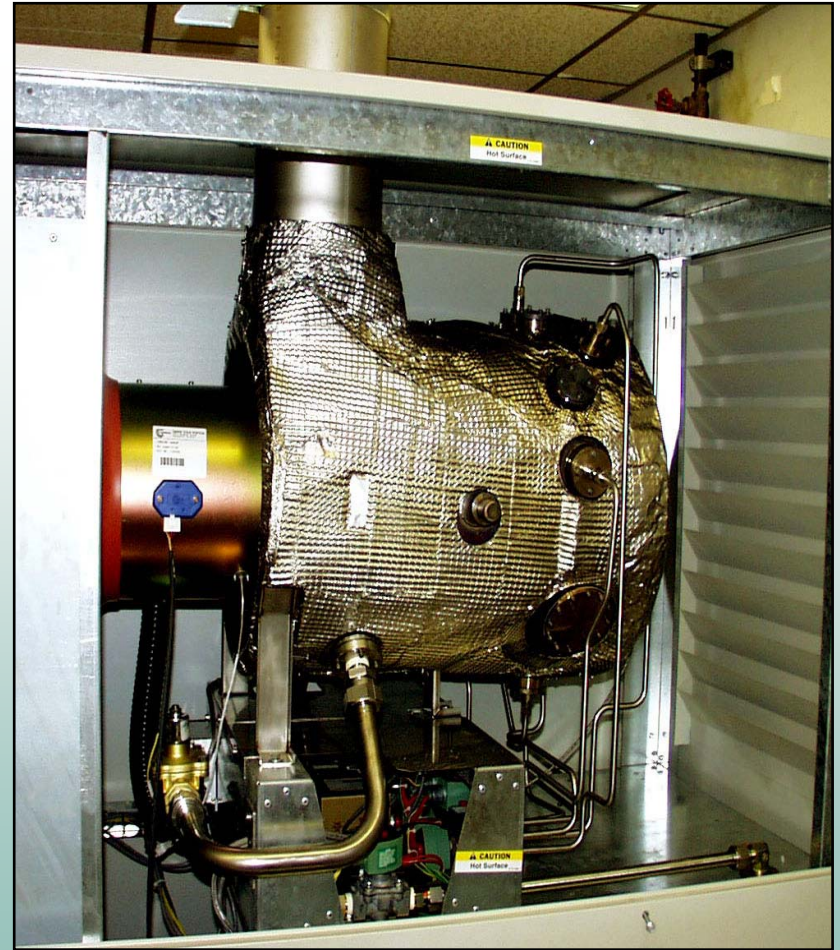
Red line → boundary for fine-grained (rolled, foil-like material) at 700°C

Grain size effect → attributed to diffusion of Cr in alloys

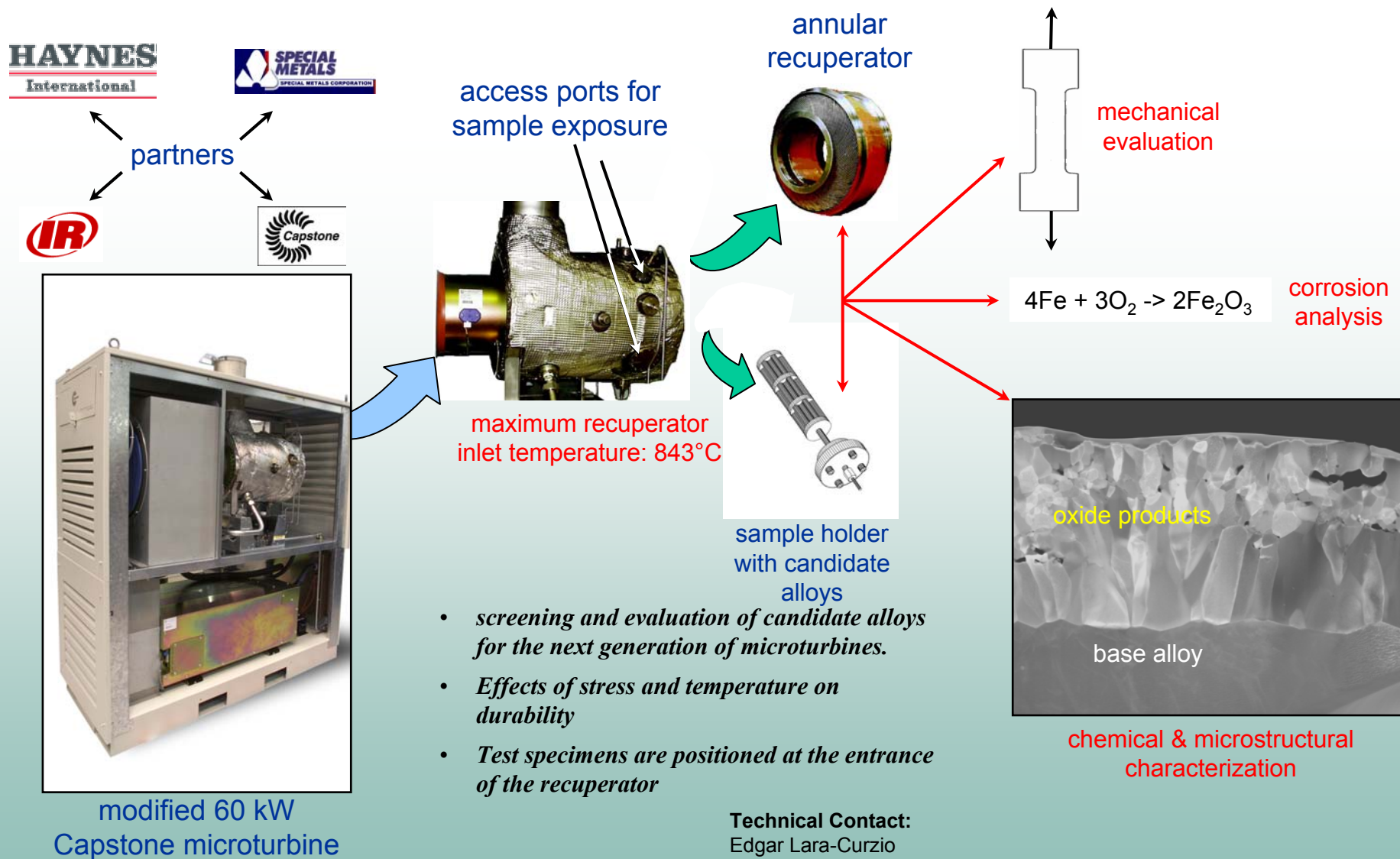
Beneficial Ni effect → to improve 347SS, increase Cr and/or Ni

Boundaries may be further altered by minor element alloying (Mn, Si, ??)

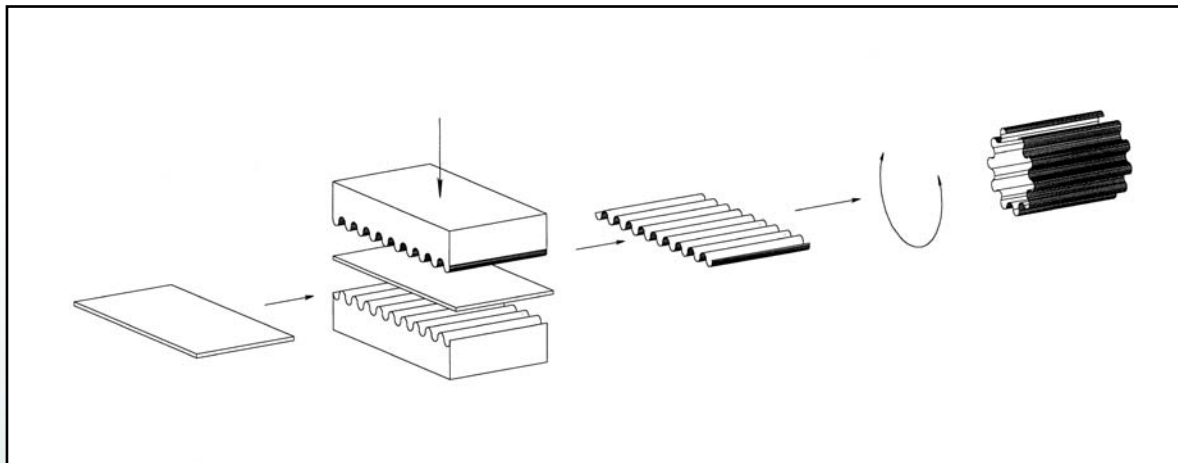
New Recuperator Testing and Evaluation Facility at ORNL



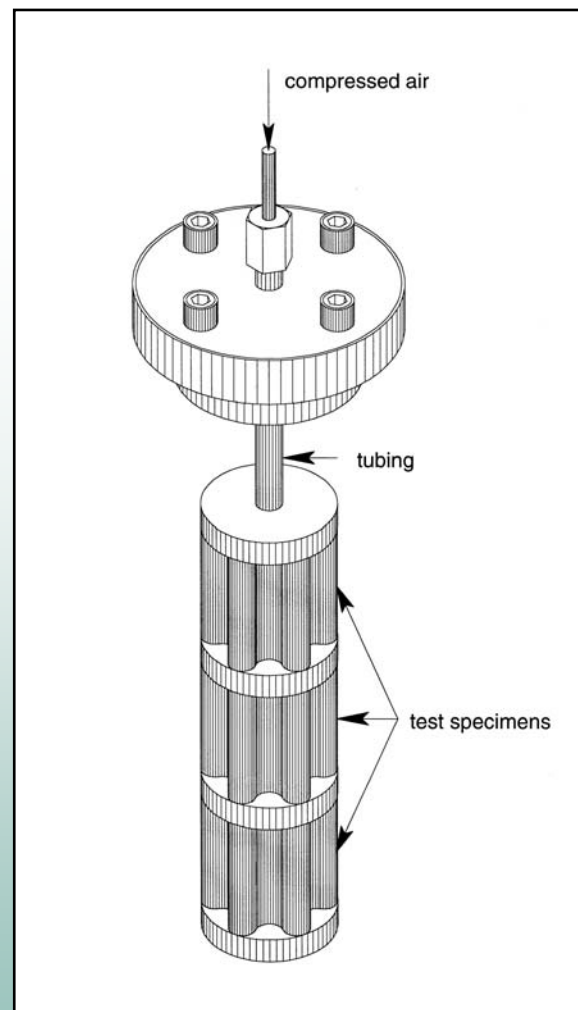
ORNL's Microturbine Recuperator Test Facility



ORNL's Microturbine Recuperator Test Facility



- *Thin foils are stamped to reproduce manufacturing (cold work) conditions.*
- *Specimens are rolled and welded to sample holder to obtain closed cylindrical geometry.*
- *Test specimens are stressed mechanically by internal pressurization.*



sample holder

OAK RIDGE NATIONAL LABORATORY

U. S. DEPARTMENT OF ENERGY

Oak Ridge National Laboratory
U.S. Department of Energy

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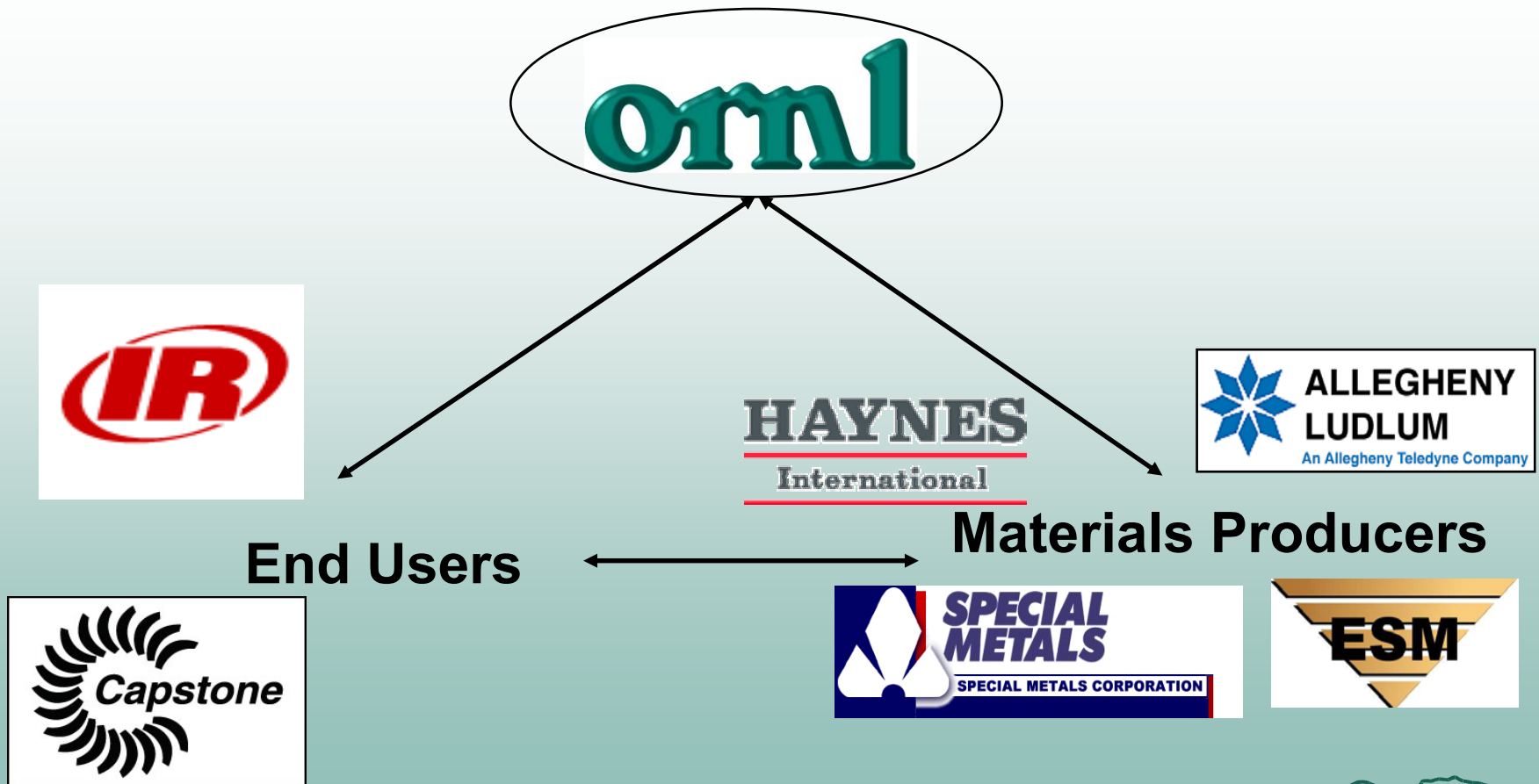
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Advanced Recuperator Materials Program Emphasis

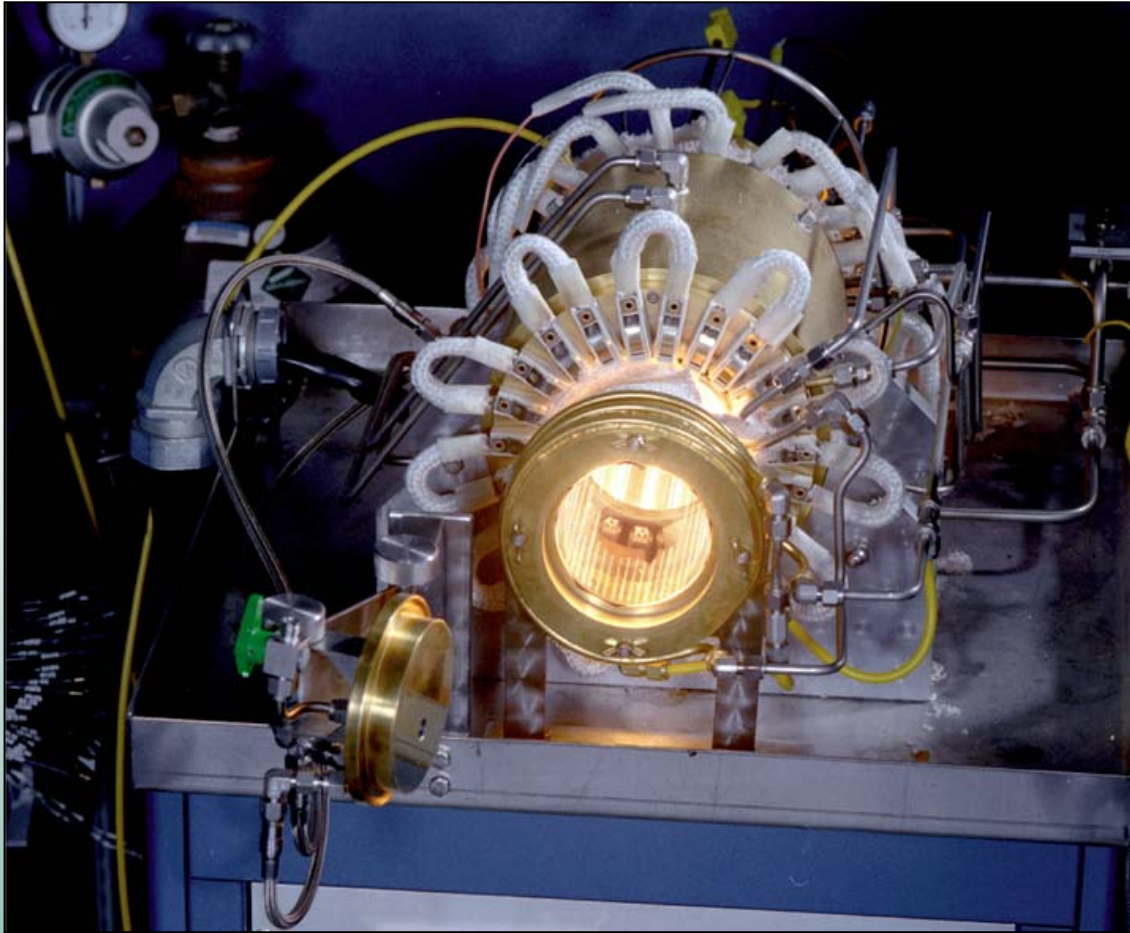
- Analyze fresh and service-exposed components to consistently benchmark the materials performance needs for various advanced microturbine recuperator technologies
- Work with OEMs and materials producers to make recuperators from commercially available advanced stainless alloys
- Develop new, modified 347 stainless steels and alloys
- Begin commercial scale-up of most promising cost-effective new alternatives to 347 stainless steel
- Corrosion Testing
- Materials Testing and Evaluation

Feedback from Microturbine OEM's Spurred Development of Modified 347 Steels with Engineered Microstructures

Materials R&D Capabilities and Expertise



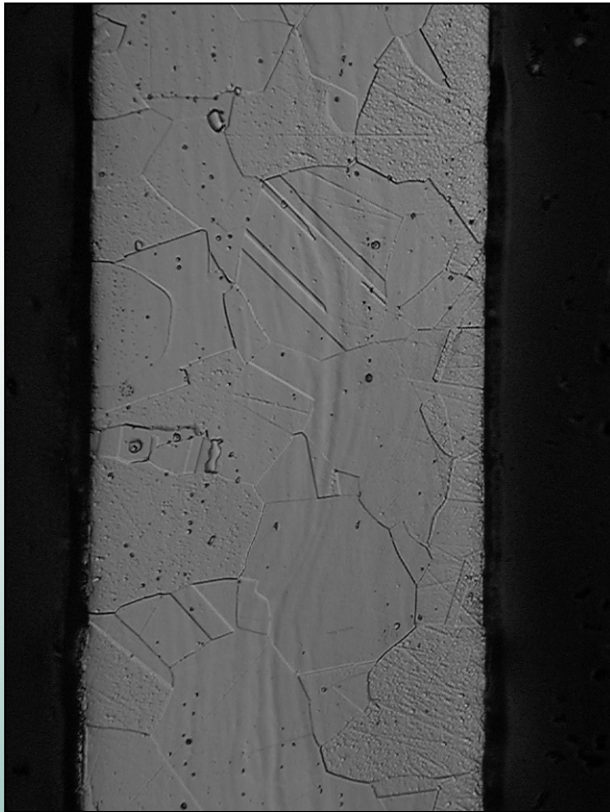
Unique ORNL Laboratory-Scale Processing Equipment Used For Accurate Simulation of Commercial CAL Foil Processing



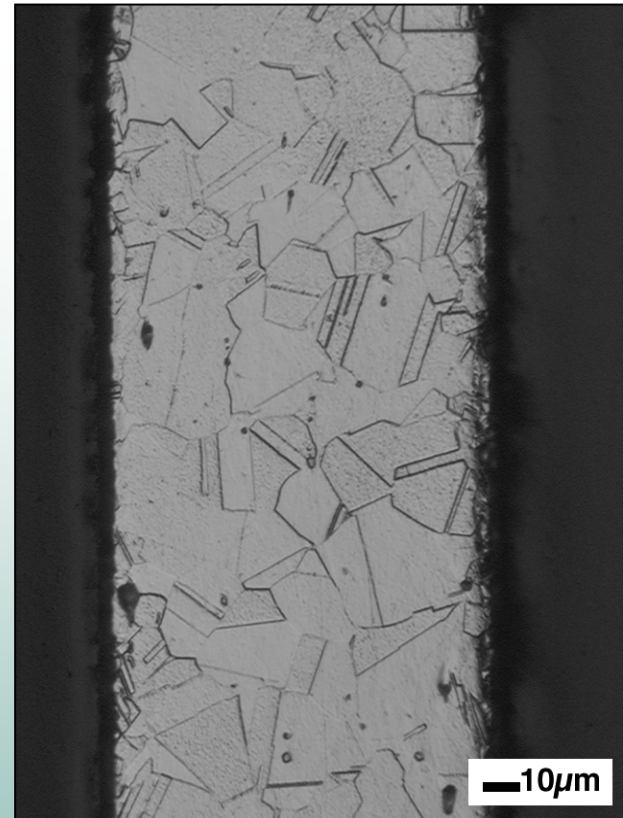
Radiant-Heating Furnace

- high-intensity Tungsten-Halogen lamps
 - Ar-4% H₂ atmosphere

Microstructures are “Engineered” to Control Grain Size and the Fine Precipitation Behavior Within the Grains

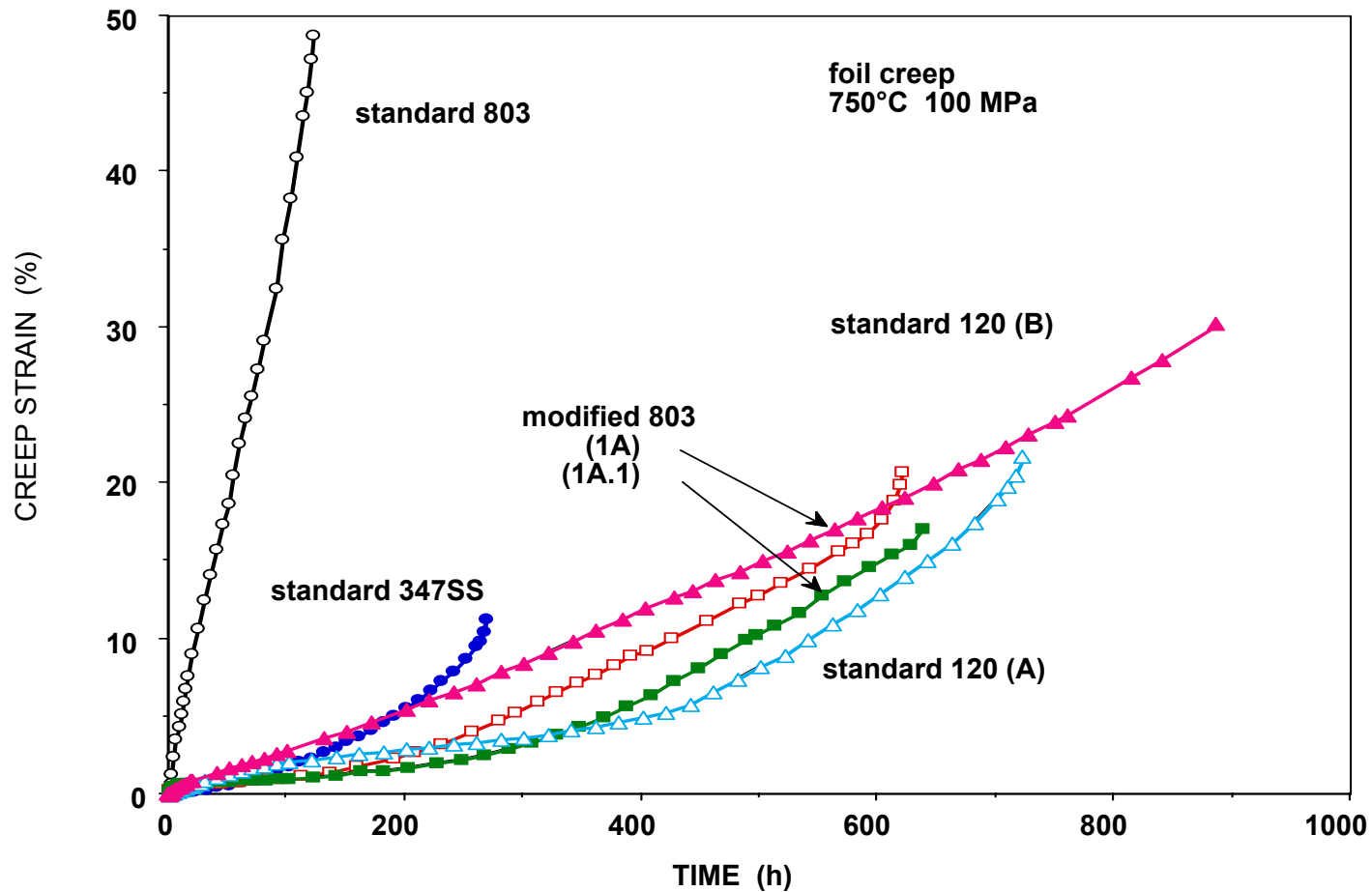


**Commercial 347 steel
ORNL processing**

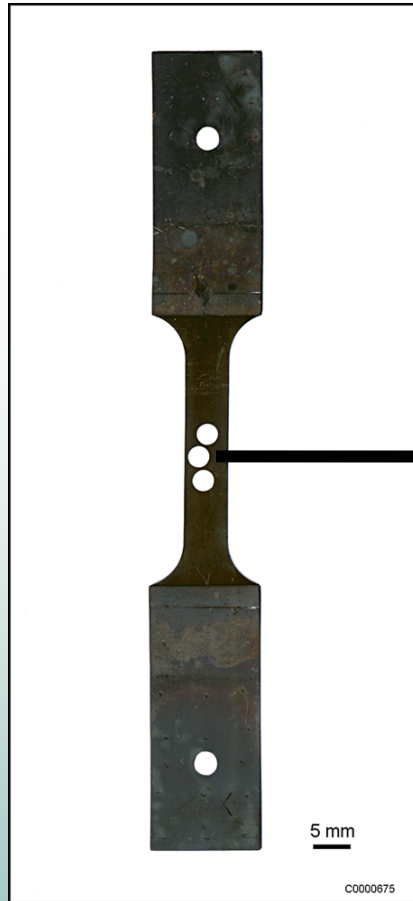


**Special Metals alloy 740 (thermie-alloy)
ORNL processing**

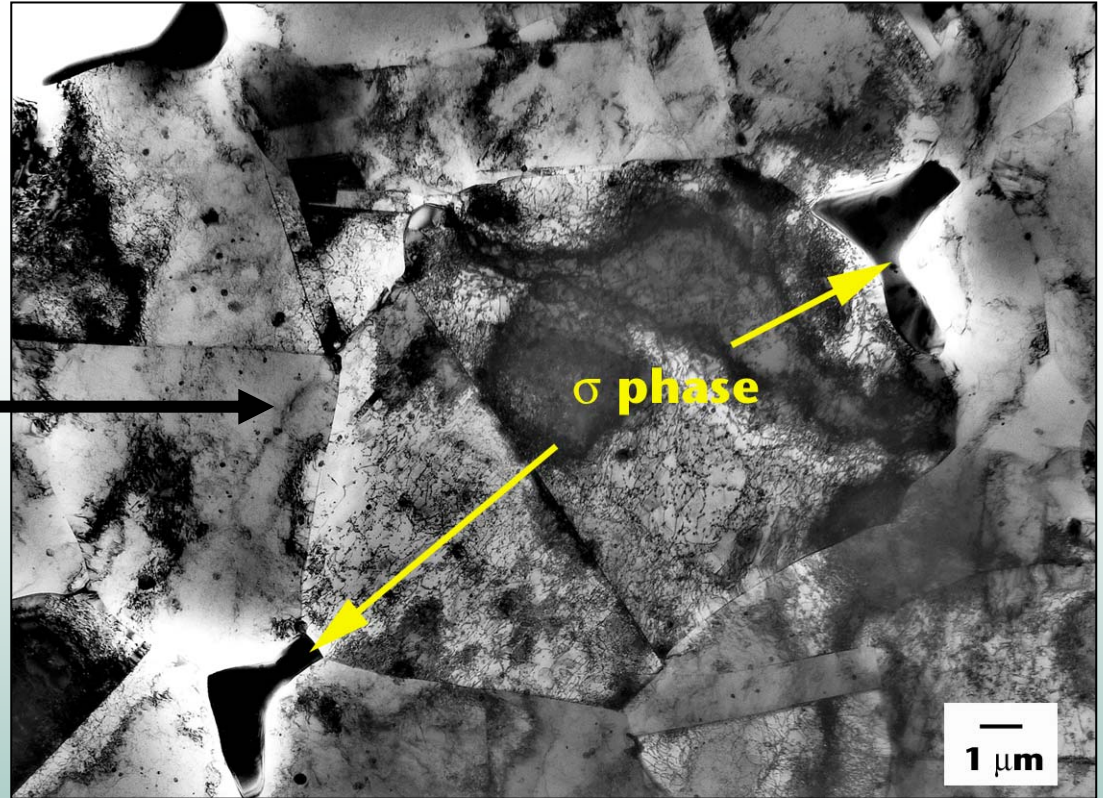
HR 120 and Modified 803 are High Performance Upgrades at Moderate Cost for Creep Resistant Foils



TEM Analysis Of Creep-Tested 347 Stainless Steel Foils Helps Guide Development of “Engineered Microstructures”

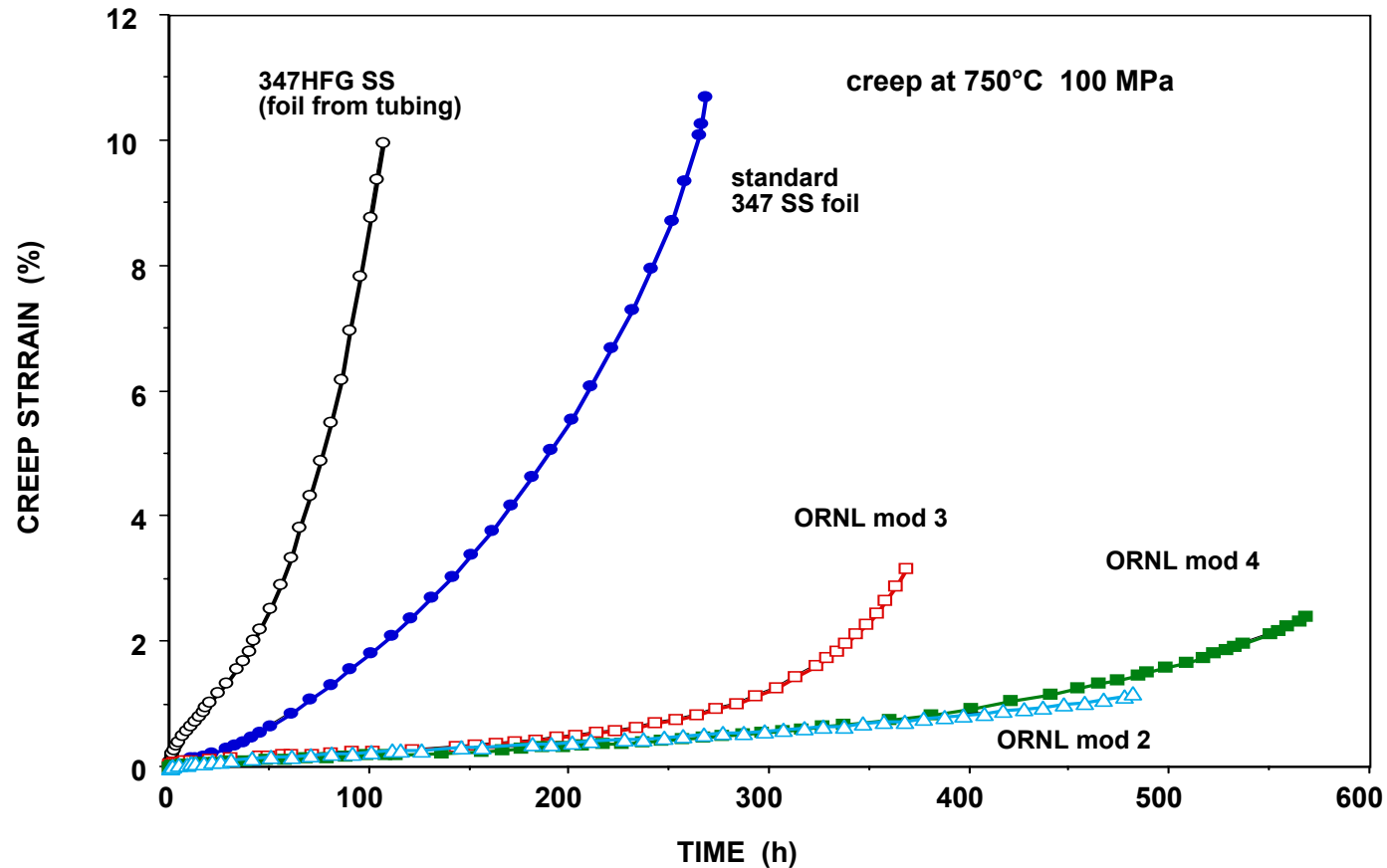


standard 347 foil,
creep tested for ~ 500 h at 704°C



TEM image

Alloy Development for “Engineered Microstructures” Can Dramatically Improve the Creep Resistance of Foils



Advanced Recuperator Materials Program

Additional and Future Work

- Test advanced alloys in Recuperator Test Facility
- Include commercial materials (347 steel, advanced alloys) in creep screening to complete study
- Screen weldability of modified 347 steels and advanced alloys relative to standard 347 steel
- Screen room-temperature tensile of as-processed (manufacturability) and aged (ductility loss) of modified 347 steels and advanced alloys
- Establish the effects or resistance to water vapor corrosion for modified 347 steels and advanced alloys